A Companion to Urban Economics
Edited by Richard J. Arnott, Daniel P. McMillen

CHAPTER FIVE

The Spatial Pattern of Land Use in the United States

Elena G. Irwin and Nancy E. Bockstael

5.1 Introduction

There is currently great interest in understanding and managing the impacts of land-use changes on individual and social well-being. This interest stems from concerns over fiscal, economic, environmental, and social issues related to changes in the spatial pattern of urban land use, including urban decentralization and the conversion of rural land to low-density urban uses. Understanding the forces that affect land-use change requires first getting the facts right. In this chapter, we attempt to describe changes in land-use patterns in the United States over the past several decades and to a lesser extent link them to economic theories designed to explain these changes. In pursuing this course, we draw on papers that have empirically measured land-use patterns or empirically tested economic theories about those patterns. With regard to some issues, the results are robust. But with regard to others, most notably those related to low-density development, considerable uncertainty remains, uncertainty that can be traced to data problems that continue to plague land-use analysis.

The chapter begins by presenting data on the major land uses of the USA and changes in those land uses in the recent past, especially conversion of rural to urban land. Some basic facts are examined regarding urban land, including its amount, regional variation, and density, and questions are raised about the ability of current data to measure current land-use phenomena accurately. To illustrate the potential problems, we draw on high-resolution land-use data available for the state of Maryland. We then review what we believe to be major trends in urban land-use changes that have received both theoretical and empirical attention in the economics literature. Some thoughts on the current state of knowledge regarding urban land-use trends, the limitations of available information, and the potential biases that may result from these limitations are included in the conclusions.

5.2 LAND-USE PATTERNS AND CHANGES IN PATTERNS

5.2.1 Major land uses

According to a recent report by the Economic Research Service of the US Department of Agriculture (2003), rural land constitutes the vast majority of the 1.9 billion acres comprising the continental USA. As of 1997, rangeland comprised 30.5 percent, forest 29.2 percent, and cropland 24 percent. In comparison, only 3.4 percent was considered to be urban land; that is, any developed land with infrastructure. Recreation and wildlife areas (largely national and state parks, forests, and wilderness areas) accounted for another 5 percent. Substantial regional variations exist in these shares, as described in Figure 5.1.

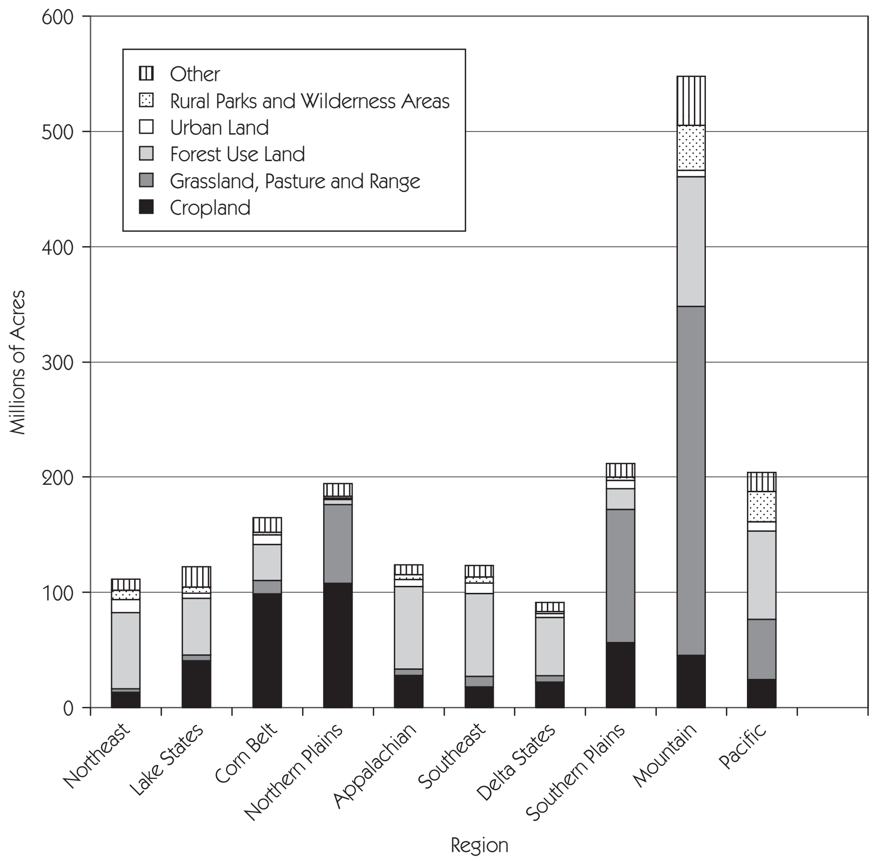


Figure 5.1 Major land uses by region of the USA in 1997.
Source: US Department of Agriculture (2003)

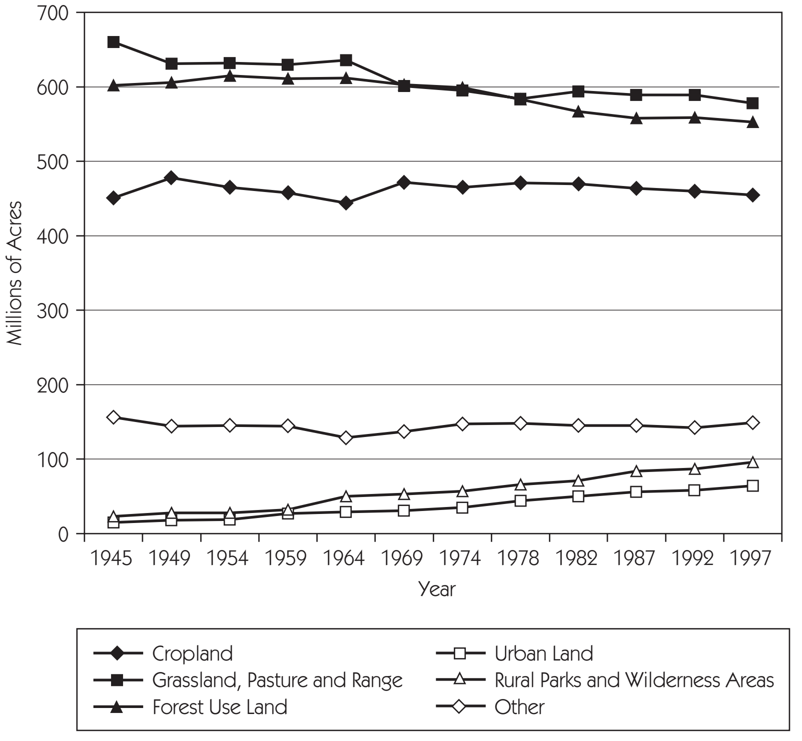


Figure 5.2 Major land uses in the continental USA from 1945 to 1997.
Source: US Department of Agriculture (2003)

We draw on this same report to illustrate trends in major land-use classes over time (Figure 5.2). According to the US Department of Agriculture (USDA), urban, recreational and wilderness lands have expanded steadily since World War II, grazing land and forests have declined, and cropland has remained relatively stable, having varied by no more than 8 percent over the period.

The aggregate statistics conceal considerable movement among land-use categories. Table 5.1, also from the same USDA source, reports that between 1982 and 1992, far more transitions occurred *among* the agricultural/forest categories than from these categories to urban uses. Of the 57.8 million acres of rural land that changed land use, 54 percent (31 million acres) was converted to another rural land use, 11 percent (6.6 million acres) to federally owned land, and 23 percent (13.1 million acres) to an urban land use. Approximately 25 percent of this rural to urban conversion involved "prime farmland" as classified by USDA. However, no significant amount of land is reported to have moved out of the urban land-use category during the period. According to these statistics, urban development appears to be effectively irreversible.

Although 20 percent of the stock of *urban* land in 1992 had been rural as of 1982, these rural land losses represented only about 1 percent of the stock of *rural*

Table 5.1 US land-use transitions, 1982–92 (millions of acres)

		1992					
		Cropland	Rangeland	Forest	Urban	Federal	Other
1982	Cropland	526	3.5	11.7	6.1	1.3	4.1
	Rangeland	8.8	391.7	1.5	1.9	3.3	1.4
	Forest	4.4	1.1	379.6	5.1	2	1.6
	Urban	0	0	0	51.9	0	0
	Federal	0.7	2	0.7	0	401.1	0.2
	Other	2.4	0.3	1.6	0.2	0.3	74.3

Source: US Department of Agriculture (2003)

land as of 1982. Based on the figures in Table 5.1, annual rates of conversion to urban land were 0.1 percent for all rural land, 0.11 percent for cropland, 0.05 percent for rangeland, and 0.13 percent for forest land. Although some estimates of urban land and conversion rates are higher, as we review below, none of these studies supports the popular notion that rural lands are disappearing at "alarming" rates. Yet, rural lands may be locally, if not globally, scarce – especially in the vicinity of expanding urban areas. This suggests that, from the perspective of the majority of the population, rural land may indeed be disappearing rapidly.

5.2.2 Revisiting estimates of total urban land

In the previous section we relied on US Department of Agriculture (2003) reported figures, compiled from nine federal agencies. But this obscures the remarkable variation that exists among estimates of urban land. Recent estimates of the amount of urban land in the continental USA in the early to mid-1990s have ranged from 1.1 percent to 7.2 percent of the total land area. Estimates of the average annual increase in urban land over the past 20–25 years vary from a low of 0.75 million acres to a high of 2.1 million acres. The disparities are due to differences in spatial resolution and accuracy of data, and to the different methods of data categorization. They are also due to differences in the definition of urban (or developed) land. While defining "what is urban" is relatively clear in the built-up areas of a city, the distinction becomes more difficult as the density of built structures declines. One house on a 100-acre farm is clearly rural land, but what do we call the same land if it is divided into a 5-acre minimum lot subdivision with 20 houses? This is not a trivial question, as the amount of low-density development has been increasing dramatically over the past few decades. USDA estimates that between 1994 and 1997, 10–22 acre lot sizes accounted for 55 percent of the increase in land dedicated to housing in the USA, and lots greater than 1 acre accounted for over 90 percent of this land (Heimlich & Anderson 2001, p. 14).

As of 2000, the US Census counts as urban all land that is located within an Urbanized Area (UA) or Urban Cluster (UC), delineations based on density thresholds and minimum populations. (UCs contain 2,500–50,000 people, and UAs contain at least 50,000 people, with both having cores with a density of at least 1,000 people per square mile.) Although not a direct measure of urban land area, these data are one of the very few sources for nationally consistent estimates of urban areas over time, making them the most commonly used data to track urban land change.

Problems with using the Census definition to measure urban land are well known. Undeveloped land, such as parks and other open space, located within a UC or UA will be counted as developed; developed land outside the UC and UA polygons will be omitted. To examine the possible magnitude of these errors, we compare the 2000 Census data with higher-resolution data on land use in Maryland, produced by the Maryland Department of Planning (MDP). These data are not perfect, but they are superior to anything else we have. They are based on a combination of high-altitude aerial photography and satellite imagery, and are further refined using parcel-level data from a digitized version of the state Division of Taxation and Assessment database. These data are particularly useful because they include several categories of residential land, including low-density development of 0.2 to 2.0 dwelling units per acre. Figure 5.3 illustrates the spatial comparison of Census UA and UC boundaries (designated by the black lines) versus MDP-designated developed areas. The existence of white space within the Census urban boundaries denotes open space categorized by Census as urban and the gray areas outside these boundaries indicate developed land that is missed by the Census definition. The comparison illustrates that in Maryland, where low- and medium-density development at the rural–urban fringe is common, the Census definition misses large tracts of developed land. Statewide, approximately 675,000 acres are common to both the Census and MDP designations of urban land, but approximately 501,000 acres considered undeveloped by the state mapping process fall within an UA or UC, and about 492,000 acres considered developed by MDP fall outside these Census areas.

The seriousness of the two types of errors varies across counties in a systematic way. Table 5.2 shows that the more urbanized a county, the greater is the percentage of undeveloped land that is counted as urban using Census urban designations. Conversely, the less urban a county, the greater is the percentage of developed land that is misclassified as rural. Even in the most urbanized counties, 38 percent of low-density residential land is missed by Census urban designations. This proportion grows to 89 percent in the least urbanized counties.

The magnitude of error is not surprising. Nelson (1992) reports that during the period from 1960 to 1990, population growth in exurban counties (regions outside established urban areas, but within their “commutershed”) outpaced suburban and urban population growth. According to Heimlich and Anderson (2001, p. 14), nearly 80 percent of residential land developed between 1994 and 1997 was located outside of metropolitan areas.

In an effort to address the omission of low-density development, US Department of Agriculture (2003) has used the American Housing Survey (AHS) to

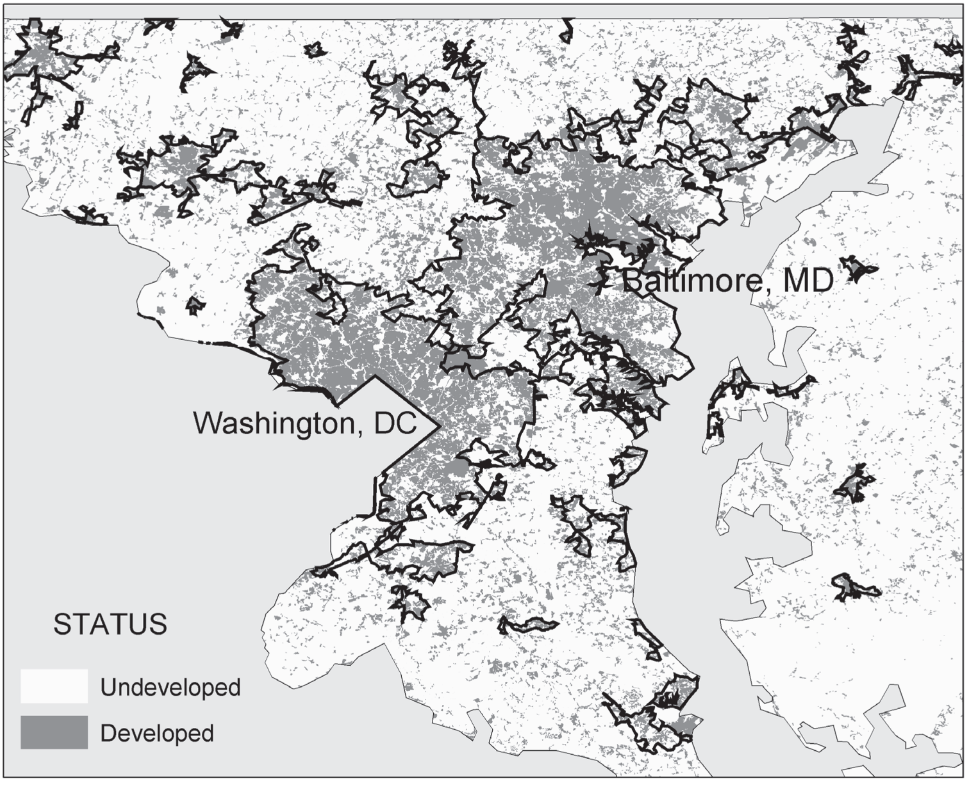


Figure 5.3 A comparison of MDP developed land and US Census Bureau urban areas, central and eastern Maryland, 2000.
Sources: US Census Bureau, 2000; Maryland Department of Planning (MDP), 2000

estimate rural residential land, defined as nonfarm land consisting of houses and associated lots located outside of urban areas. Using the Census definition of urban areas, alone, urban land was estimated at 64 million acres (3.4 percent of the continental USA) in 1997, and growing by an average of 1.07 million acres per year since 1980. Including the nonfarm rural residential areas identified by the AHS raises the estimate to 137 million acres or 7.2 percent – with an estimated 2.1 million acres of growth in urban land per year.

The National Resources Inventory (NRI), yet another source of land-use data, estimates land cover/use at national and subnational scales based on a longitudinal sample of about 800,000 sites located on nonfederal US land. Developed land categories include large (greater than 10 acres) and small (0.25 to 10 acres) urban and built-up areas, where the latter term refers to areas of residential, commercial, industrial or institutional use, but includes nonurban uses of less than 10 acres completely surrounded by urban land. A third developed category is rural transportation networks. According to these definitions, the total developed land area in the continental USA was 97.6 million acres (5 percent of the total land

Table 5.2 A comparison of US Census Bureau urban areas and Maryland Department of Planning (MDP) developed land by county type, Maryland, 2000

Large urban counties

		MDP						
		Commercial/ high-density residential		Low-density residential		Undeveloped		Total
Census		Acres	Percent	Acres	Percent	Acres	Percent	
Rural	Acres	18,969	6%	25,169	8%	272,493	86%	45%
	Percent	8%		38%		68%		
Urban	Acres	217,946	57%	40,660	11%	125,477	33%	55%
	Percent	92%		62%		32%		
Total		236,915	34%	65,829	9%	397,970	57%	700,714

Large suburban and exurban counties

		MDP						
		Commercial/ high-density residential		Low-density residential		Undeveloped		Total
Census		Acres	Percent	Acres	Percent	Acres	Percent	
Rural	Acres	61,576	4%	148,246	9%	1,366,585	87%	78%
	Percent	21%		68%		92%		
Urban	Acres	238,592	55%	71,087	16%	126,080	29%	22%
	Percent	79%		32%		8%		
Total		300,168	15%	219,333	11%	1,492,665	74%	2,012,166

Small urban and nonmetropolitan counties

		MDP						
		Commercial/ high-density residential		Low-density residential		Undeveloped		Total
Census		Acres	Percent	Acres	Percent	Acres	Percent	
Rural	Acres	48,432	2%	141,064	5%	2,821,980	94%	96%
	Percent	47%		89%		98%		
Urban	Acres	55,071	41%	17,314	13%	60,511	46%	4%
	Percent	53%		11%		2%		
Total		103,503	3%	158,378	5%	2,882,491	92%	3,144,372

Maryland county types: Large urban counties = central counties in metropolitan areas of 1 million or more. Large suburban and exurban counties = all outlying counties in metropolitan areas of 1 million or more. Small urban and nonmetropolitan counties = central counties in metropolitan areas of 250,000 people or less and all nonmetropolitan counties.
Sources: US Census Bureau, 2000; Maryland Department of Planning (MDP), 2000

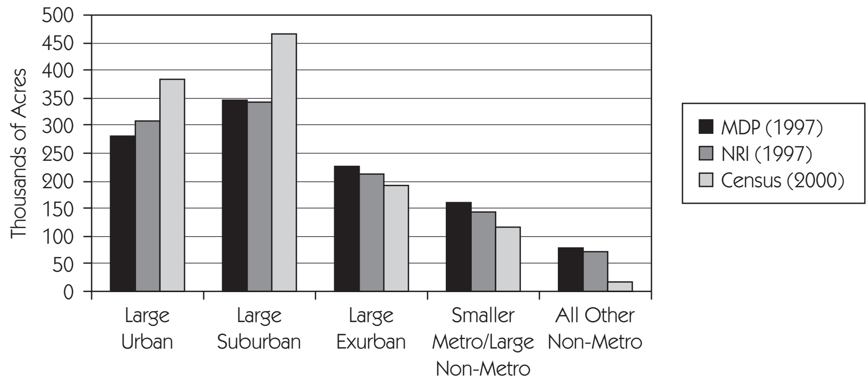


Figure 5.4 A comparison of total urban land estimates for Maryland by county type.

Maryland county types: Large urban = central counties in metropolitan areas of 1 million population or more. Large suburban = adjacent counties in metropolitan areas of 1 million population or more. Large exurban = nonadjacent counties in metropolitan areas of 1 million population or more. Smaller metro/large nonmetro = counties in metropolitan areas of 250,000 population or less or nonmetropolitan counties that are adjacent to metropolitan areas with 20,000 urban population or more. All other nonmetro = nonmetropolitan counties that are adjacent to metropolitan areas with 2,500 to 20,000 urban population.

Sources: Maryland Department of Planning (MDP), 1997; National Resources Inventory (NRI), 1997; US Census Bureau, 2000

area) in 1997, with an estimated average increase of 1.65 million acres per year since 1982. Small sample sizes prevent these data from being reliable estimates of land use even at the county level. In addition, federal lands, which account for about 20 percent of the land area of the continental USA, are excluded and therefore development on federal lands is omitted from these estimates. But despite its limitations, a comparison of the 1997 NRI estimates (the latest for which we have regional figures) with 1997 Maryland Department of Planning (MDP) land-use data yields a surprising correspondence at aggregate levels for groups of counties. The estimated amount of urban land for the most urban counties is overestimated by about 9.5 percent and underestimated for the least urban counties by about 11.6 percent, discrepancies far smaller than that between Census and MDP data (see Figure 5.4). Whether this correspondence would be sustained in other geographical areas is difficult to say. In any event, the fact that NRI data cannot be compared at a resolution less than the multiple county level prevents its use in analysis of *spatial pattern* at anything but the coarsest level.

The appeal of Census data is its availability in fairly consistent form over time. Satellite imagery promises to provide another consistent time series of land-use data. Both the National Land Cover Data (NLCD) and the Multi-Resolution Land Characteristics (MRLC) Consortium data are based on satellite images from 1992, and scenes from the new NLCD based on images from 2001 are beginning to be released. In an attempt to estimate land-use change over time without relying on Census data, Burchfield, Overman, Puga, and Turner (forthcoming) compared 1992 NLCD data with urban land estimates from the Geographic Information Retrieval and Analysis System (GIRAS). The latter, based on aerial photography from 1971 to 1982 (circa 1976), shows approximately 24 million acres in urban land, as compared to the NLCD estimates of about 36 million acres in 1992.

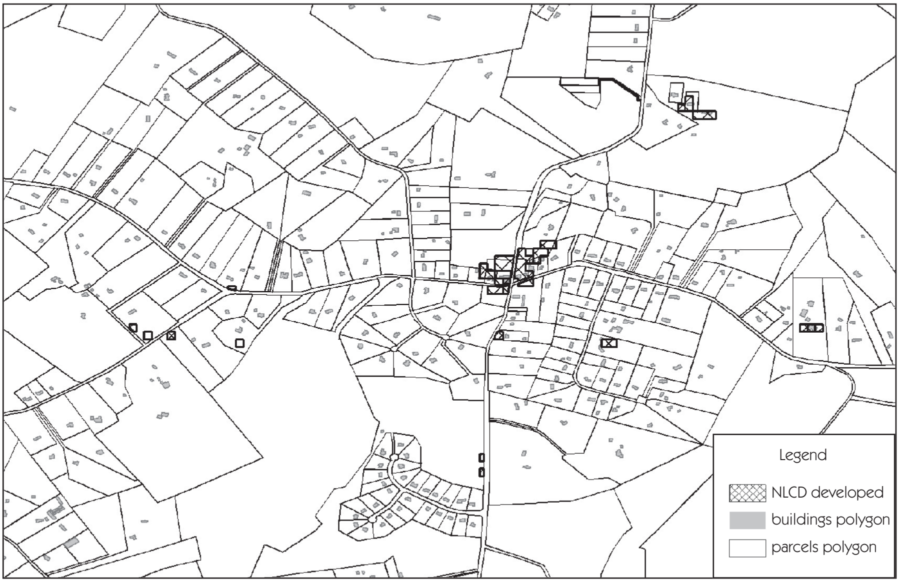
Satellite imagery is an appealing source of land-use data, but it is substantively different from aerial photography or other "on the ground" sources. It relates strictly to land cover that does not always map nicely into land-use categories and is impaired by cloud cover and tree canopy. Translation of images is dependent on classification methods, with the most notable difficulties arising, once again, in the recognition of low-density residential use, where the footprint of the built structure corresponds to a very small percentage of the land parcel (McCauley & Goetz 2004). Figure 5.5 provides a visual representation of this point for two representative areas in Howard County, Maryland, that vary by development density. Areas that are developed (including developed open space and low-, medium- and high-intensity developed) according to NLCD data from 2001 are overlaid with land-parcel boundaries and building footprints, both produced by the Howard County Office of Planning. The results illustrate the ability of the satellite data to record the location of buildings in more densely developed areas, which corresponds reasonably well to the land use of parcels in these areas (Figure 5.5(a)), but the very limited ability of satellite data to capture the presence of buildings and development in less densely developed areas (Figure 5.5(b)).

These images are representative of the ability of satellite data to record higher- versus lower-density development. We compared the NLCD 2001 land-cover data with the Maryland Department of Planning (MDP) 2000 data for a nine-county region in central Maryland that encompasses urban, suburban, and exurban areas of the Washington, DC – Baltimore region. While 24 percent of all land identified by MDP as being in medium- or high-density residential land use is classified as undeveloped by NLCD, 82 percent of all land identified by MDP as low-density residential land is classified as undeveloped by NLCD.

5.2.3 Urban density estimates

Given the popular lament that land is being developed at faster rates than the rate of population growth, we consider the evidence from studies that have measured urban development density and some that have tracked changes in these densities across time. While some studies have defined urban density as the ratio of population to total land area, we consider only those that measure population relative to the amount of urban land, which provides a more accurate measure of the land-use pattern. The evidence supports the notion of declining densities, although results are subject to caveats about how well data sources measure developed land. Using a combination of NRI urban land designations and Census population extrapolations, Fulton, Pendall, Nguyen, and Harrison (2001) estimate a decline in average density from 5.0 to 4.2 people per urbanized acre for 281 metropolitan areas over the period from 1982 to 1997. According to

(a)



(b)

Figure 5.5 A comparison of NLCD 2001 developed land cover and Howard County, Maryland, building footprints and parcel boundaries. (a) More densely developed area, eastern Howard County; (b) less densely developed area, western Howard County.

Sources: US Geological Survey, National Land Cover Dataset, 2001; Howard County Office of Planning, 2002 their figures, only 6 percent of these metropolitan areas did not decrease in density during this time period. Outside metropolitan areas, they estimate declines in average density from 4.5 to 3.6 people per urbanized acre. Glaeser and Kahn (2004) suggest similar average density declines from 5.3 to 4.8 people per acre between 1982 and 1995, calculated for 68 select metropolitan areas.

As always, regional trends differ. Fulton, Pendall, Nguyen, and Harrison (2001) find that while the rest of the country grew less dense over time, metropolitan areas in the West became more dense, adding population at approximately three times the density of other regions. High growth in both population and amount of developed land in the South contrasts with low population growth and large increases in developed land in much of the Midwest and Northeast, contradicting the hypothesis that high rates of population growth contribute to low-density development. While many fast-growing areas also grew rapidly in developed land (e.g., Atlanta, Seattle, and Los Angeles), many of the metropolitan areas with large increases in developed land have experienced only modest population growth (e.g., Chicago, Cleveland, Pittsburgh, and St Louis). Comparing the 1976 GIRAS and 1992 NLCD data sets, Burchfield, Overman, Puga, and Turner (forthcoming) determined that no state's aggregate urban areas increased in density, while many states witnessed substantial decreases between the mid-1970s and the early 1990s.

5.3 Theories and Evidence on Trends in Urban Land-Use Patterns

Despite inconsistencies in data, a consensus has emerged on one dominant trend – the decentralization of urban areas. Two longstanding theories of urban location, the monocentric model and the Tiebout model of household location, offer broad explanations of population decentralization. The monocentric model predicts that decentralization occurs as the result of a decrease in transportation costs or rising incomes, both of which have occurred over the past century. The Tiebout model of household location views households as "voting with their feet" by moving to the local jurisdiction providing the bundle of public goods and services that maximizes their utility subject to their budget constraint, where the latter includes the local jurisdictional tax needed to pay for public goods. Under this theory, perceived urban ills (e.g., higher crime rates, lower school quality, more congestion, racial tensions) push households with higher incomes to live in lower-density, suburban communities that offer higher-quality public goods and services and more homogeneous populations. Both the monocentric model and Tiebout hypothesis suggest that the extent of decentralization may differ across cities due to differences in income levels and commuting costs or differing levels of urban services and amenities.

Researchers attempting to empirically test hypotheses about changing decentralization have encountered difficulties in characterizing the spatial representation of density. The most basic representation of density pattern, based on the monocentric model, is a population density gradient that measures the change in population per unit area as distance from the central city increases. Changes in density patterns over time are represented by changes in the slope or curvature of the density gradient. But researchers have found that decentralization can manifest itself in more complex forms that are much harder to represent using a simple density gradient measure, including suburban subcentering, "fractal cities," and fragmented residential development. A consensus does not exist on the prevalence of some of these more complex urban patterns, due in part to differences in the types of data used to measure these patterns and the spatial scale of analysis. The fact that decentralization is dynamic rather than static adds a further challenge. Measurement inherently demands consistent, spatially explicit time series data. These data must be able to detect changes in density (such as infill) in already developed areas and account for the changing spatial extent of the analysis as development emerges in previously rural areas.

5.3.1 Urban density gradients

Urban spatial pattern has often been characterized in terms of a population density gradient – the slope of the relationship between population per unit area and distance to city center (for a comprehensive review, see the chapter by Daniel McMillen in this volume). Studies have typically found these functions to be downward sloping with distance and flattening substantially over time, supporting the notion of increasing decentralization of cities.

McDonald (1989) reviews attempts to explain differences in gradients across cities and identifies a few consistent findings. Some have no obvious connection to either the monocentric or Tiebout models, such as the prevalence of relatively flatter gradients in urban areas with large populations and relatively steeper gradients in older urban areas. But flatter gradients do appear to be associated with higher household incomes, as the monocentric city model suggests, and substandard housing and high ratios of nonwhite households, as the Tiebout theory suggests. Jordan, Ross, and Usowski (1998) find that, for a subset of cities that best matches the monocentric structure, the rate of decentralization in the 1980s was significantly accelerated by the proportion of city residents living in poverty. Anas, Arnott, and Small (1998) estimate a 26 percent decline in the average density gradient for US cities due to changes in transport costs and average income levels between 1950 and 1970, but find that declining transportation costs and increases in income levels do not come close to explaining the full magnitude of the decentralization that has occurred.

Density gradient analysis implicitly assumes continuous development, but in reality a nontrivial amount of vacant land exists in most cities, being more prevalent with distance from the city center. Mieszkowski and Smith (1991) investigate the extent to which declining density gradients are a spurious result due to the spatial pattern of vacant land, and do so using 1980 Census tract data in Houston. By ignoring vacant land, they estimate a density gradient of −0.05, only a fraction of the gross density gradient (−0.148) estimated including vacant land.

Researchers have also come to question the appropriateness of the commonly used negative exponential density function, suggested by monocentric city theory, and have employed more flexible functional forms. Others have suggested that the negative density gradient, if it does provide a good fit to the data, is simply an artifact of history. Urban patterns are seen as the result of a cumulative aggregation of past development, with densities reflecting the economic conditions that prevailed at the time the houses were constructed. In contrast to the monocentric theory, which takes capital as malleable, development may be largely irreversible and changes in densities through redevelopment the exception rather than the rule. Irreversibility implies that densities need not be monotonically decreasing with distance, and if redevelopment does happen, it may produce discontinuities in the density gradient.

5.3.2 Suburban subcenters

Up to this point, we have treated urban spatial pattern as though it were solely a function of residential land use. A fundamental dimension of urban structure and urban decentralization is the spatial pattern of economic activity – often measured in terms of employment. Comparisons of density gradients of employment over time typically support the decentralization hypothesis, but simple density gradients may be even less applicable for employment than for population. Empirical tests across cities of polycentric versus monocentric urban form almost uniformly reject the monocentric assumption. If most urban areas are polycentric in nature, then an important dimension of changing urban spatial pattern is the emergence of subcenters or edge cities – concentrations of employment outside the central business district.

Many theoretical models explain subcentering as the result of a tension between agglomeration economies, providing incentives for firms to cluster together in space, and countervailing dispersive forces, such as rising land rents, competition among firms, congestion externalities, or employee commuting costs. The resulting size, location, and number of clusters depend on the relative strengths of the agglomerative and offsetting forces, and on how rapidly these effects diminish with increasing distances between firms. Other theories of edge city location explain their emergence as the result of strategic actions by large-scale developers (or municipalities) who engineer the relocation of many individual firms and households through coordinated development. Decisions regarding edge city location are modeled as a function of transportation cost/land rent trade-offs, as well as other distance-dependent considerations.

Empirical work on urban subcenters has focused chiefly on questions of measurement: How does one identify a subcenter, so that the number and size of subcenters can be compared over time and over cities and the determinants of subcenters identified? Varying definitions have been proffered in the literature based on different total employment and employment density thresholds. Guiliano and Small's (1991) definition claims to be less arbitrary and more consistently applicable across the USA. They define a subcenter as a zone with employment density of at least 10 workers per acre and total employment of at least 10,000, yielding 28 distinct subcenters in Los Angeles, 15 in Chicago, and 22 in San Francisco as of 1990. By this definition, most large metropolitan areas can be characterized as containing 20 or more subcenters (Anas, Arnott & Small 1998).

By reworking Fujita and Ogawa's (1982) theoretical model of urban spatial structure, McMillen and Smith (2003) show that the number of subcenters should increase as total population and per unit commuting costs increase. Using a locally weighted regression technique to identify subcenters, they estimate a model of the number of subcenters within an urban area and find support for these hypotheses. The model predicts that a city's first subcenter will form at an approximate population level of 2.68 million and the second subcenter at about 6.74 million.

5.3.3 Discontinuous residential development

Residential development is commonly perceived as occurring in a leapfrog or discontinuous pattern, especially in outer suburban and exurban areas. The magnitude of these patterns depends on the spatial scale at which they are analyzed. In describing urban land-use change using the circa 1976 GIRAS and 1992 NLCD data, Burchfield, Overman, Puga, and Turner (forthcoming) determine that 75 percent of observed land conversion to urban use was located within 1.5 km of existing development. This suggests that, if leapfrogging does occur, it occurs at a finer scale. Using parcel- or subdivision-level data, studies such as Irwin and Bockstael (2002), Carrión-Flores and Irwin (2004), and Stanilov (2002) have found pervasive patterns of dispersion, fragmentation, and low-density development, usually in exurban areas. Evidence suggests that these patterns are persistent over time; for example, Carrión-Flores and Irwin find that despite a dramatic increase in the amount of residential land between 1956 and 1996 in their Ohio exurban study region, residential development maintained a dispersed pattern rather than infilling over time. However, because these studies look at parcel- and subdivision-level data, they are necessarily limited in their geographical extent.

Leapfrogging has been traditionally explained within the context of the monocentric model as the result of a dynamically efficient market process in which development is irreversible and future returns to development are expected to increase at a sufficient rate. This prevalent theory of leapfrogging implies that leapfrogging will be temporary at any given location, but that the development "frontier" may always exhibit this pattern. Some have demonstrated that uncertainty and heterogeneity in expectations can lead to "transition zones" that are permanently developed in a discontinuous pattern (Mills 1981; Bar-Ilan & Strange 1996).

Peiser (1989) tests an implication of this theory: that land skipped-over and left vacant is developed later at higher densities than it would have been had leapfrogging not occurred. Limiting his observations to residential developments from three existing suburbs (two in Washington, DC, and one in Dallas, Texas), he finds that more recently built houses are constructed on smaller lots. However, Peiser does not control for the effect of land-use controls, such as zoning, and cautions that the regulatory environment can have a substantial impact on these findings.

Alternative theories of discontinuous or leapfrog development appeal to the existence of spatial externalities among households that can have agglomerative and dispersive effects. Agglomerative forces may consist of the benefits of neighborhoods and the public infrastructure that they provide or the desire to minimize commuting costs to a central location, while dispersive forces include the disutility of congestion and the appeal of open space amenities. Simulations of an agent-based model of household location by Parker and Meretsky (2004) demonstrate that such forces can generate fragmentation in areas that are closer to the urban fringe.

Using a hazard model of land conversion and parcel-level data from Maryland, Irwin and Bockstael (2002) provide empirical evidence of negative externalities associated with surrounding development. Carrión-Flores and Irwin (2004) find that preferences for low-density living and limited agglomeration economies around the central city have increased the dispersion of new residential development, but that positive externalities associated with neighboring residential and commercial development have moderated these effects. However, land heterogeneity and land-use policies, such as urban boundaries, zoning, and preserved open space, have been found to have an effect on fragmentation levels as well (e.g., Irwin, Bell & Geoghegan 2003).

5.3.4 Other dimensions of urban patterns

Up to this point, we have studiously avoided the use of the word "sprawl" despite its popularity in the press and in a growing number of academic articles. While most feel that the term "sprawl" is not a sufficiently definitive concept upon which to base analysis, many see it as synonymous with the multidimensionality of urban land-use patterns. No universal definition of sprawl exists, but most attempts include concepts of low density and a lack of contiguity, compactness, and centrality. Most researchers attempting its measurement agree that sprawl is not a discrete outcome, but rather a matter of degree.

Two recent national studies have attempted to measure multidimensional aspects of land-use pattern. Galster, Hanson, Ratcliffe, Wolman, Coleman, and Freihage (2001) define sprawl as a pattern of land use in an urbanized area that exhibits low levels of some combination of eight distinct dimensions: density, contiguity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. They measure six of these using 1990 Census data from UAs at the block level aggregated up to 0.5- and 1.0-mile square grid cells for a sample of 13 UAs and compute a composite score for each of these urbanized areas. Using a composite of their measures, Atlanta is ranked as the most, and New York City as the least, sprawling city. But true to the complexity of these concepts, cities tend to be ranked differently depending on the "sprawl" dimension considered. For example, Los Angeles is ranked eighth of 13 in overall severity but first in terms of its lack of clustering.

Ewing, Pendall, and Chen (2002) draw on multiple data sources to measure four dimensions that they say characterize sprawl in 83 US metropolitan areas (with a minimum population of 0.5 million in 2000): low-density development, segregated land uses, lack of significant centers, and poor accessibility. Many of the individual variables used to compute the scores are similar to other studies, but some are more unique; for example, the percentage of residents with "satisfactory" shopping within 1 mile; the percentage of residents with a public elementary school within 1 mile; the degree of "balance" within Census-defined traffic analysis zones (TAZs) between jobs and people; and the percentage of the metropolitan population relating to centers or subcenters within the same metropolitan area. New York City, San Francisco, Boston, and Portland are found to be compact in all dimensions, whereas Atlanta, Raleigh–Durham, North Carolina, and Riverside–San Bernardino, California, are sprawling in all dimensions. But similar to the previous study, rankings for most cities vary considerably over different dimensions. In addition, the direction of change in these measures between 1990 and 2000 is inconsistent for any given city.

Using various definitions of "sprawl," researchers have correlated hypothesized causes or consequences of sprawl. Fulton, Pendall, Nguyen, and Harrison (2001) find that metropolitan areas with a high proportions of black or Hispanic populations and greater political fragmentation of local governments are more sprawling (in terms of the ratio of population to urban land), whereas those with more prime farmland, geographical constraints (e.g., a coastline or international border), and a higher proportion of households serviced by public sewer are less sprawling. Using a similar sprawl measure, Pendall (1999) finds that low-density zoning and building caps are associated with more sprawl, whereas adequate public facility requirements, which require developers to support the cost of public services incurred by the development, are associated with less sprawl. Studying the correlation between sprawl and hypothesized consequences, Kahn (2001) finds evidence that sprawl (as measured by employment decentralization) has made housing more affordable and provided greater equality of housing consumption between black and white households.

A number of other studies, many from geography and some from landscape ecology, have considered other dimensions of urban form that provide evidence of its spatial complexity. For example, by applying a variety of spatial statistics to various urban land data (including Census and remotely sensed data), researchers have found evidence of "fractal" cities (e.g., Batty & Xi 1996) and the changing complexity of form across urban gradients (Luck & Wu 2002).

5.4 CONCLUSIONS

A popular perception of land-use change is one of rapid loss of open space, increases in land conversion at rates that far exceed population increases, decentralization of urban areas accompanied by increasingly low-density new development, and substantial fragmentation of the landscape, particularly in urban fringe areas. Is there evidence to support these perceptions? And, equally important, do data exist that make tests of these propositions possible?

Our review of urban land-use trends in the USA suggests that empirical evidence exists to support some of these broad perceptions, but not all. The existing literature suggests the following:

- Urban land comprises a small percentage of the total land area of the continental USA, but estimates from the mid-1990s vary from a low of 1.1 percent to a high of 7.2 percent.
- The amount of urban land has steadily increased over time, but estimates of the increase over the past 20–25 years vary from a low of 0.75 million acres to a high of 2.1 million acres per year.
- Average development densities have declined over time in many, but not all, areas.
- Urban decentralization and subcentering are well-documented trends that have occurred in most, if not all, metropolitan areas of the USA. However, conclusions regarding the extent of decentralization and the number and type of subcenters vary depending on data and methodology.
- Leapfrog or discontinuous development patterns appear to be pervasive at a fine scale (e.g., parcel-level) in some outer suburban and exurban areas, but are not prevalent at coarser scales of analysis. However, the limited geographical extent of these studies and varying spatial scales prohibits conclusions regarding the overall dominance of this trend.
- There is little consensus on the definition and measurement of sprawl. The empirical evidence is highly dependent on the researcher's definition of sprawl and the data used to measure it.
- Exurban development is the least studied of the urban land-use trends and the most difficult to measure. Nonetheless, evidence exists that substantial proportions of recent development activity is of the low-density form and in regions outside established urban areas. Due to the low-density nature of this development, the impact on population redistribution to these areas is far less than the impact on land conversion.

Our review also documents the variability in the evidence depending on data source. In fact, the empirical evidence on urban land-use patterns is subject to several potential sources of bias and must be viewed with these limitations in mind:

- First, all results are dependent on the type and source of the data. For example, an analysis of urban land-use patterns using Census-defined urban areas, satellite imagery, aerial photography, or tax assessment records will employ different definitions of urban land and thus will generate quite different results. Given the undercounting of low-density development by both Census-defined urban areas and land-cover data derived from satellite imagery, many existing national level studies underrepresent this aspect of urban land-use pattern.
- Second, results are highly dependent on the scale of analysis. National-level statistics obscure what can be dramatic regional changes in landscape, which in turn can mask changes at a highly disaggregated scale. In addition, the process of urban pattern change is itself likely to be scale-dependent, implying that the spatial characteristics of patterns are not constant across spatial scales. It is entirely reasonable to find pervasive leapfrog patterns of development

at highly disaggregate levels that disappear at more aggregate scales of analysis.

- Third, analyses of these urban trends are dependent on the spatial extent of the data. The spatial extent of the most commonly used data – urban areas from the US Census – is defined by a minimum threshold for population density and thus does not include outlying areas that are growing and changing, but that are developed at lower densities. Omission of these outer suburban and exurban areas from analysis biases results by suggesting greater centralization, less fragmentation, and a lower proportion of low-density urban land than is actually the case. For these reasons, we suspect that the trends of decentralization, leapfrogging, and low-density exurban development are more pervasive than the current evidence suggests.

Acknowledgments

We thank Dan McMillen, Mathew Turner, and an anonymous reviewer for helpful suggestions. Any remaining errors are our own. This research was supported in part by NASA under Grant #NAG511149 and by the US Environmental Protection Agency under STAR Grant # R-82801201.

Bibliography

Anas, A., Arnott, R., and Small, K. 1998: Urban spatial structure. *Journal of Economic Literature*, 36 (September), 1,426–64.

Bar-Ilan, A. and Strange, W. 1996: Urban development with lags. *Journal of Urban Economics*, 39, 87–113.

Batty, M. and Xie, Y. 1996: Preliminary evidence for a theory of the fractal city. *Environment and Planning A*, 28(10), 1,745–62.

Burchfield, M., Overman, H. G., Puga, D., and Turner, M. A. forthcoming: Sprawl: a portrait from space. *Quarterly Journal of Economics*.

Carrión-Flores, C. and Irwin, E. G. 2004: Determinants of residential land conversion and sprawl at the rural–urban fringe. *American Journal of Agricultural Economics*, 86(4), 889–904.

Ewing, R., Pendall, R., and Chen, D. 2002: Measuring sprawl and its impact. Volume 1. Smart growth America. Retrieved February 2004 from www.smartgrowthamerica.com/sprawlindex/MeasuringSprawlTechnical.pdf

Fujita, M. and Ogawa, H. 1982: Multiple equilibria and structural transition of non-monocentric urban configurations. *Regional Science and Urban Economics*, 12, 161–96.

Fulton, W., Pendall, R., Nguyen, M., and Harrison, A. 2001: Who sprawls the most? How growth patterns differ across the U.S., Brookings Institute, Center on Urban and Metropolitan Policy, Washington, DC.

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H. R., Coleman, S., and Freihage, J. 2001: Wrestling sprawl to the ground: defining and measuring an elusive concept. *Housing Policy Debate*, 12(4), 681–717.

Giuliano, G. and Small, K. A. 1991: Subcenters in the Los Angeles region. *Regional Science and Urban Economics*, 21(2), 163–82.

Glaeser, E. L. and Kahn, M. 2004: Sprawl and urban growth. In J. V. Henderson and J.-F. Thisse (eds.), *Handbook of Urban and Regional Economics*, vol. 4: *Cities and Geography*. Amsterdam: Elsevier North-Holland, 2, 481–527.

Heimlich, R. E. and Anderson, W. D. 2001: Development at the urban fringe and beyond: impacts on agriculture and rural land. Agricultural Economic Report 803, Economic Research Service, US Department of Agriculture, Washington, DC.

Howard County Office of Planning (various dates): County Land Parcel Boundary and Building Footprint GIS Database; www.co.ho.md.us/DPZ/DPZ_Homepage.htm

Irwin, E. G. and Bockstael, N. E. 2002: Interacting agents, spatial externalities and the endogenous evolution of land use patterns. *Journal of Economic Geography*, 2(1), 31–54.

Irwin, E. G., Bell, K., and Geoghegan, J. 2003: Modeling and managing urban growth at the rural–urban fringe: a parcel-level model of residential land use change. *Agricultural and Resource Economics Review*, 32(1), 83–102.

Jordon, S., Ross, J., and Usowski, K. 1998: US suburbanization in the 1980s. *Regional Science and Urban Economics*, 28, 611–27.

Kahn, M. 2001: Does sprawl reduce the black/white consumption gap? *Housing Policy Debate*, 12(1), 77–86.

Luck, M. and Wu, J. 2002: A gradient analysis of urban landscape pattern: a case study from the Phoenix Metropolitan Region, Arizona, USA. *Landscape Ecology*, 17, 327–39.

Maryland Department of Planning 1997: Land Use Land Cover Maps. Baltimore, MD; www.mdp.state.md.us

Maryland Department of Planning 2000: MdProperty View. Statewide Property Map and Parcel Database. Baltimore, MD; www.mdp.state.md.us/data.mdview.htm

McCauley, S. and Goetz, S. J. 2004: Mapping residential density patterns using multi-temporal LandSat data and decision-tree classifier. *International Journal of Remote Sensing*, 25(6), 1,077–94.

McDonald, J. 1989: Econometric studies of suburban population density: a survey. *Journal of Urban Economics*, 26(3), 361–85.

McMillen, D. P. and Smith, S. C. 2003: The number of subcenters in large urban areas. *Journal of Urban Economics*, 53, 321–38.

Mieszkowski, P. and Smith, B. 1991: Analyzing urban decentralization: the case of Houston. *Regional Science and Urban Economics*, 21, 183–99.

Mills, D. 1981: Growth, speculation, and sprawl in a monocentric city. *Journal of Urban Economics*, 10, 201–26.

National Resources Inventory (NRI), Natural Resources Conservation Service, US Department of Agriculture (various dates); www.nrcs.usda.gov/technical/land/nri01/nri01lu.html

Nelson, A. C. 1992: Characterizing exurbia. *Journal of Planning Literature*, 6, 350–68.

Parker, D. and Meretsky, V. 2004: Measuring pattern outcomes in an agent-based model of edge-effect externalities using spatial metrics. *Agriculture, Ecosystems, and Environment*, 101(2–3), 233–50.

Peiser, R. B. 1989: Density and urban sprawl. *Land Economics*, 65, 193–204.

Pendall, R. 1999: Do land use controls cause sprawl? *Environment and Planning B*, 26, 555–71.

Stanilov, K. 2002: Postwar trends, land-cover changes, and patterns of suburban development: the case of Greater Seattle. *Environment and Planning B – Planning & Design*, 29(2), 173–95.

US Census Bureau (US Department of Commerce) 2000: TIGER/Line files; www.census.gov/geo/www/tiger/index.html

US Department of Agriculture 2003: *Agricultural Resources and Environmental Indicators*. Ag Handbook No. AH722, Washington, DC.

US Geological Survey (US Department of the Interior) 2001: National Land Cover Dataset; http://landcover.usgs.gov/natllandcover.asp